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TEMPERATURE-SENSING TELEMETRY SYSTEM FOR UNRESTRAINED RHESUS MONKEYS (MACACA MULATTA)

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TEMPERATURE-SENSING TELEMETRY SYSTEM FOR UNRESTRAINED RHESUS MONKEYS (MACACA MULATTA)

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FOREWORD

The temperature-sensing telemetry system described in this paper was developed and constructed by technical personnel of the Biomedical Engineering Branch. Work was accomplished in support of project No. 7930.

The experiment reported herein was conducted by Captain Jere M. Phillips, Veterinary Sciences Division, from September 1966 through December 1966.

The report was prepared in the Biomedical Engineering Branch and was submitted for publication on 4 May 1967.

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The experiment reported herein was conducted according to the "Principles of Laboratory Animal Care" established by the National Society for Medical Research.

This report has been reviewed and is approved.

James B Nuttall

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Commander

ABSTRACT

The temperature-sensing telemetry system consists of three implanted transmitters (each with its own antenna system and receiver), a scanner to sample in sequence each receiver output, a frequency counter, digital recorder, and tape punch unit. The scanner, synchronized with the digital recorder, permits temperature recording from each of the three transmitters once every 5 minutes. The implant is an FM/FM (frequency-modulated subcarrier/frequency-modulated transmitter) telemetry unit operating in the 88 to 108 MHz FM broadcast band. Thermistors are used as temperature sensors. Printed circuit boards are used for component interconnection and antenna; mercury batteries are used for power. The sensor, radio frequency transmitter, and batteries are embedded in an epoxy case. Before implantation the unit is calibrated in a water bath over the temperature range of 34° to 42° C. The system has been used to automatically record digitally and continuously, temperature measurements of three unrestrained rhesus monkeys *(Macaca mulatta)* for a period of 5 weeks.

TEMPERATURE-SENSING TELEMETRY SYSTEM FOR UNRESTRAINED RHESUS MONKEYS (MACACA MULATTA)

I. INTRODUCTION

The temperature sensing telemetry system to be presented was primarily designed to record long-term temperature variations of unrestrained rhesus monkeys.

The design of an implantable temperature-sensing device presents several major problems. For small animals the implant must be physically small, lightweight, and constructed so it can be positioned to measure the best core temperature. The implant used was primarily designed to have a resolution of 0.1° C. and an operational life of 50 days. Within reason, size and weight were of secondary importance. To obtain the 0.1° C. resolution, a 14.5 kHz center frequency of the subcarrier oscillator was used.

To meet the criterion of 50-day operational life demands minimum current requirements, long battery life, and minimal implant leakage after positioning in the animal. Other investigators have reported problems due to absorption of body fluids by the implant (1, 2, 3).

Each implanted device consisted of a radio frequency (RF) transmitter, a subcarrier oscillator controlled by a thermistor, and a source of power. The specifications selected were: (a) the radio frequency of the transmitter to be within the commercial FM broadcast band (88 to 108 MHz); (b) the temperature-sensing subcarrier oscillator to sense linearly the temperature range from 34° to 42° C.; (c) the unit to use batteries and draw minimal current at 2.7 volts; (d) the unit to be implantable in the abdomen of a 3 to 5 kg. rhesus monkey and to have a minimal operational life of 35 days in the animal. An additional 15 days' life was added to allow pre- and postexperimental calibration.

II. TEMPERATURE-SENSING IMPLANT

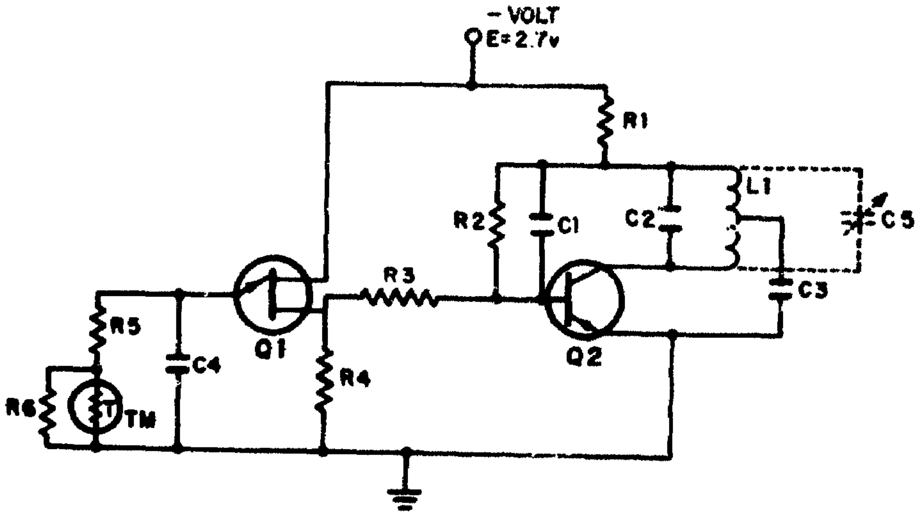
Radio frequency transmitter

The radio frequency portion of the circuit is a Hartley oscillator shown in figure 1, modulated by the subcarrier oscillator signal; the percentage of modulation is controlled by resistor R_3. The inductor of the transmitter also serves as its radiator (fig. 2), and its field pattern is shown in figure 3.

A receiver (Empire Devices model NF-105) and antenna (DM-105) were used to measure the field radiation. The antenna is placed 15 feet from the turntable on which the implant is positioned. As the implant is rotated, the radiated signal is picked up by the antenna, fed to the receiver, and recorded on an XY plotter. The linear coordinates from the XY graph are then manually plotted on polar graph paper.

Figure 3 illustrates the axis of rotation of the module and the field pattern (in microvolts per meter) as the module is rotated through its X, Y, and Z axis. From these radiation measurements, most favorable radiation appears to be the Z axis, which in turn governed the orientation of the implant within the subject.

Since the transmitters are operating within the commercial FM band, precautions must be taken to preclude operation on the frequency



Q2= 2N995
Q1= 2N2646
C1 = .001mfd.
C2= 15mmfd
C3= 15mmfd
C4= .01 mfd
C5= 1to10mmfd
R1 = CURRENT LIMITER (Approx. 2k)
R2= 27kΩ
R3= 100kΩ
R4= 1kΩ
R5= FREQUENCY SETTING SUB-CARR (0-2k)
R6= 18kΩ
TM= THERMISTOR VECO 41A11 10kΩ

FIGURE 1

Circuit diagram of RF transmitter and temperature-sensing unit.

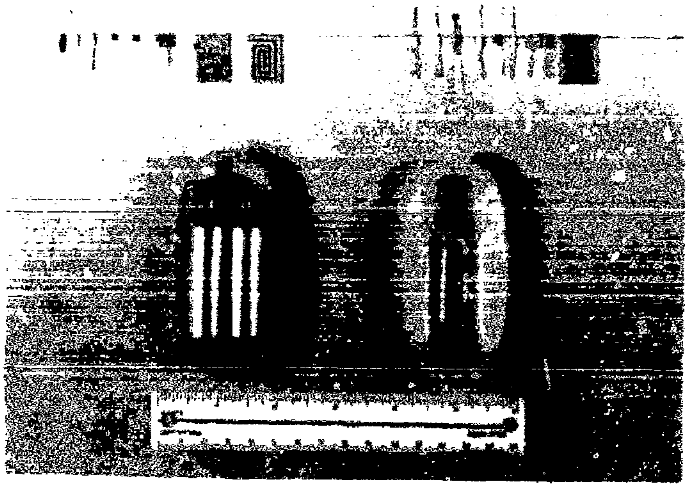


FIGURE 2

RF transmitter and temperature-sensing unit before and after being assembled.

of a local FM broadcast station. This is accomplished by use of a small variable capacitor (C_5) placed across the inductor. The frequency adjustment is also used to compensate for the effects of the embedding compounds.

Subcarrier oscillator

The temperature sensor is an RC oscillator using a unijunction transistor (Q_1), shown in figure 1. A VECO-41A11 thermistor is used as part of the oscillator's frequency-determining network. Resistors R_5 and R_6 and capacitor C_4 are chosen to provide a center frequency of 14.5 kHz at 38° C. and an operating range of 34° to 42°. A 14.5 kHz center frequency was used in order to have the required 0.1° C. resolution. Average sensitivity of six implants was 240 Hz per degree centigrade.

Power

The temperature-sensing implant is powered by two mercury cells connected in series to provide 2.7 volts (RM-12R, Mallory). Two of these cells will power an implant (drawing 2 ma. current) for 70 days. The two cells and sensing module provided an implant which is oval in shape, 8.7 by 4.0 by 2.6 cm. Total weight of the implant is 138 gm., of which 83 gm. is the weight of the two cells.

Fabrication

Figure 2 shows the number of components, including the three circuit boards, used in the implant. All components used are commercially available. One printed circuit board accommodates the components for the subcarrier oscillator; another has the components for the transmitter; and the third board has been etched to provide a spiral inductor for the transmitter. The completed module occupies 2.8 $cm.^3$ and weighs 2.5 gm.

Embedding of module circuitry and cells

Permeability of implant cases to body fluids can cause erroneous operation or lead to failure of sensor. Low moisture absorption and low toxicity are most desirable in materials used for implant cases. Past experience indicates Scotchcast brand resin No. 5 (3M Company) can best meet these two important requirements. Furthermore, this epoxy can be molded into a case for the implant.

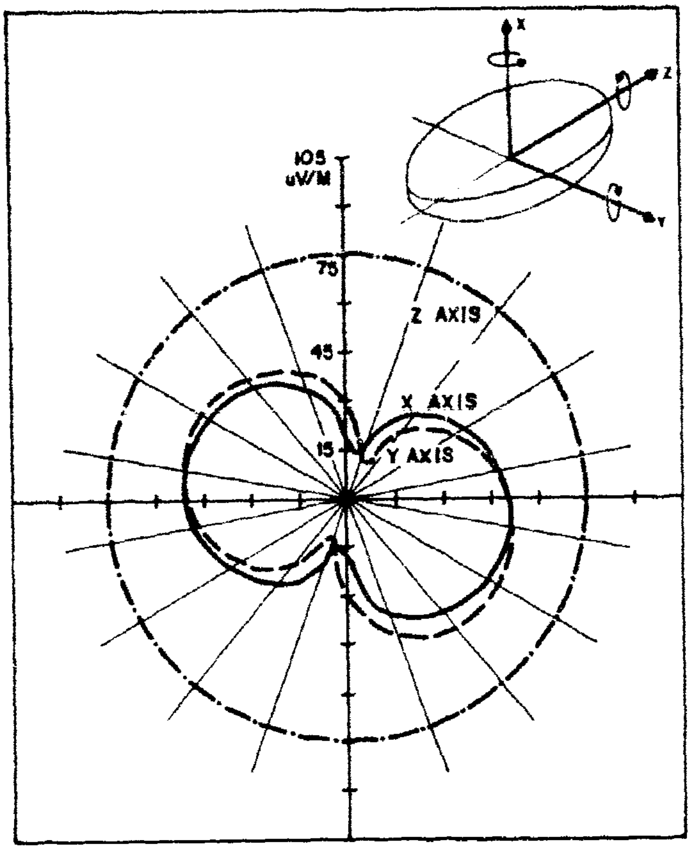


FIGURE 3

Radiation patterns of implant X, Y, and Z axis.

Two half-shells were first molded of the Scotchcast resin. To preclude pinholes in the finished cases, the epoxy resin and catalyst are placed in a vacuum jar for 15 minutes before mixing. Then they are carefully mixed and poured into the mold, which is returned to the vacuum jar to remove any entrapped air.

After the module and the two mercury cells are connected and placed in one of the half-shells, the other half-shell is placed in position and the two half-shells are sealed with Scotchcast brand resin by carefully applying the epoxy around the interface of the two half-shells.

At room temperature Scotchcast brand resin No. 5 will cure in approximately 24 hours. In an oven at an elevated temperature of 50° C., the Scotchcast resin will cure in about 3 hours.

Calibration of the implant

The implant is ready for calibration when the module circuitry and mercury cells have been sealed in the Scotchcast resin case.

First, the completed implant is subjected to a temperature step function. Time and subcarrier oscillator frequency are recorded from the beginning of the step temperature change until the subcarrier frequency stabilizes at its new value. Percentage of subcarrier frequency excursion versus time is plotted as shown in figure 4. The time constant of the implants varied from 2 to 5.4 minutes. Implants since

fabricated have time constants of less than 1 minute.

Figure 5 indicates the equipment used to precalibrate the implants. The temperature of the water bath is first brought up to 84° C., as indicated by a quartz thermometer (Dymex model DY-2801Z). The water temperature is held at 34° C. until the implant subcarrier frequency has been stable for approximately 15 minutes; then the temperature of the water bath and the subcarrier frequency are recorded. The same procedure is followed every 2° C.

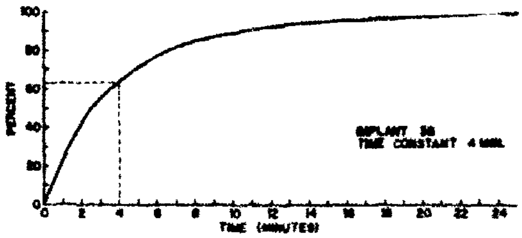


FIGURE 4

Implant percentage frequency excursion in response to temperature step function.

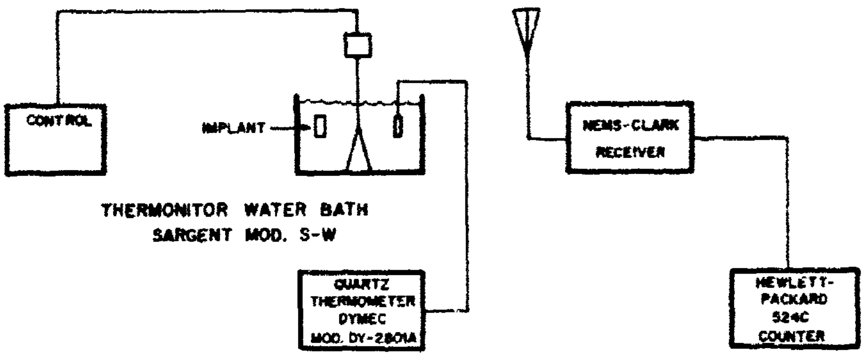


FIGURE 5

Implant calibration system.

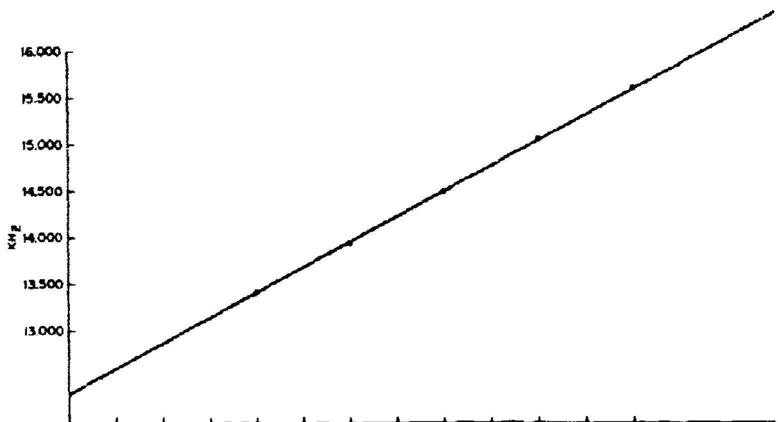


FIGURE 6

Implant calibration curve.

through the range of 34° to 42° C. The five calibration points obtained are plotted as indicated in figure 6.

The accuracy of the calibration is dependent on the temperature reading of the water bath and the measurement of the implant subcarrier frequency. The temperature of the water bath is monitored by a quartz crystal thermometer, which provides an accuracy better than ± 0.02° C. between 0° and 100° C. The frequency of the subcarrier oscillator is measured by a Hewlett-Packard 524C counter having an accuracy of ± 1 count. Both instruments are calibrated every six months with standards that are traceable to the National Bureau of Standards.

At the end of 5 weeks the implant is removed and recalibrated. If there has been a significant shift in calibration owing to decrease in battery voltage, appropriate corrections may be made. Typical implant subcarrier center frequencies varied less than 0.4% after use.

III. DATA ACQUISITION AND RECORDING SYSTEM

Antennas and receivers

A block diagram of the temperature-sensing telemetry system is shown in figure 7.

Choice of receiving antenna assembly was dictated by the following conditions:

1. Reliable reception regardless of position of primate in the cage.

2. Relative position of cage and antenna to remain fixed.

3. No interference with normal feeding or cage cleaning.

4. No major cage modification.

5. Avoidance of biting and handling of antenna wires by primates.

Several measurements were made using dipoles, whips, and multiloop antennas. Results of these measurements indicated that two square loops of wire, 10 inches on a side, placed on each side and within the cage would meet conditions 1, 2, and 3, above. In order to meet conditions 4 and 5, the square loops were constructed of square ½-inch-thick plastic (Plexiglas), 10 inches on a side, grooved around its perimeter. A No. 12 solid copper wire was placed in the groove, and the two ends of the copper wire were terminated on a BNC RF connector. After the wire was installed and the ends soldered to the BNC connector, a strip of thin plastic (Plexiglas) was glued around the perimeter of the loop covering the wire and the groove. This covered the exposed wire and thin edges that could be bitten by the primate. Figure 8 shows one of the two loops installed in a cage.

A half-wave length of coaxial cable was connected to each loop, and the coaxial cables from a pair of loops terminated at a TEE connector. From the TEE connector a single coaxial cable was connected to the receiver. The output of each receiver was fed to the input of the scanner.

Scanner-recorder

The scanner consists of a stepping switch that connects the output of each receiver in sequence to the input of a Hewlett-Packard 522 counter. Every fourth step on the switch is blank to provide a reference point in the sampling sequence. Temperature readings from the three transmitters are identified by starting at the reference point. The reading immediately after the reference point is from primate 1, followed by primates 2 and 3, in sequence. The stepping switch rests at each step for approximately 1 minute 15 seconds. This provides one temperature reading from each animal every 5 minutes. The scanner is actuated with a pulse from the Hewlett-Packard 560 digital recorder.

After the analog signal is selected by the scanner, it is fed to the counter for digitization before recording. Real time is provided in

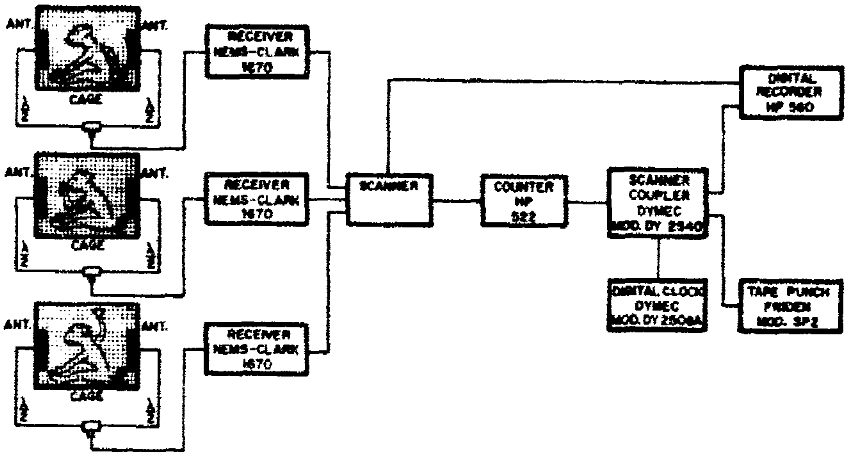


FIGURE 7
Block diagram of data acquisition and recording system.

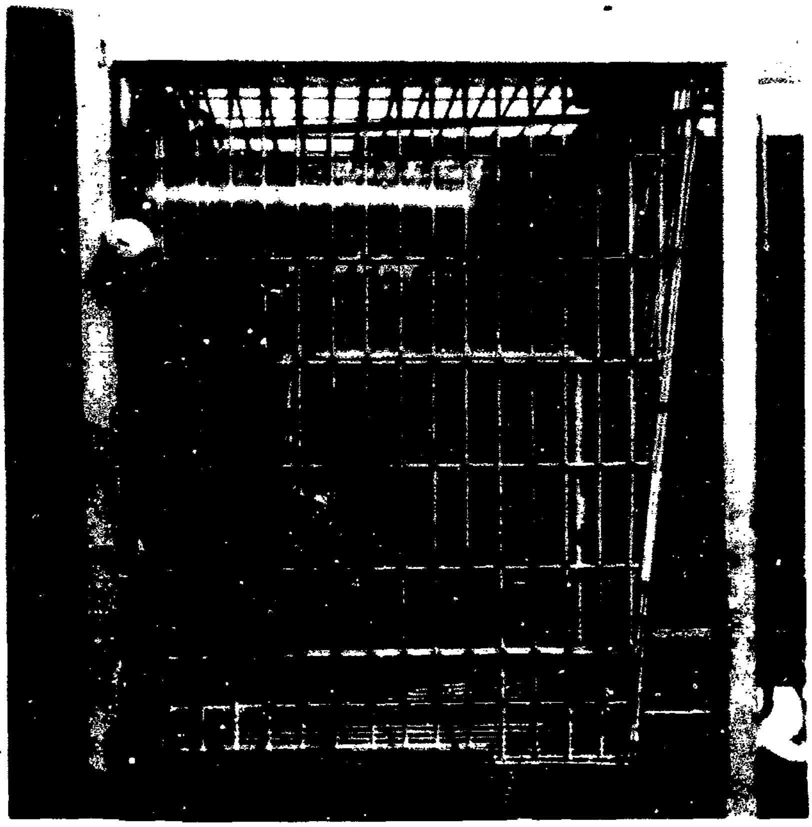


FIGURE 8
Antenna pickup loop fastened to cage.

digital form by a digital clock (Dymec model 2508A). A Dymec coupler (model DY2540) accepts and combines the digitized data from the counter and the clock and feeds the data to the Hewlett-Packard 560 digital recorder and to the Friden tape punch.

The temperature, as sensed by the implant, is now being recorded once every 5 minutes on a digital recorder for "quick look" and also is recorded on punched tape in a format suitable for computer reduction. Figure 9 shows the temperature-sensing telemetry system in operation.

IV. RESULTS

During this experiment six rhesus monkeys were used as subjects. Two runs of three primates were completed, each run lasting 5 weeks.

The greatest problem encountered during the runs was keeping implants operational within the primate. The current consumed varied between 1.2 to 2.0 ma. from implant to implant. An RM-12 mercury cell, under favorable conditions, would provide a minimal operational life of 70 days; however, in practice, it

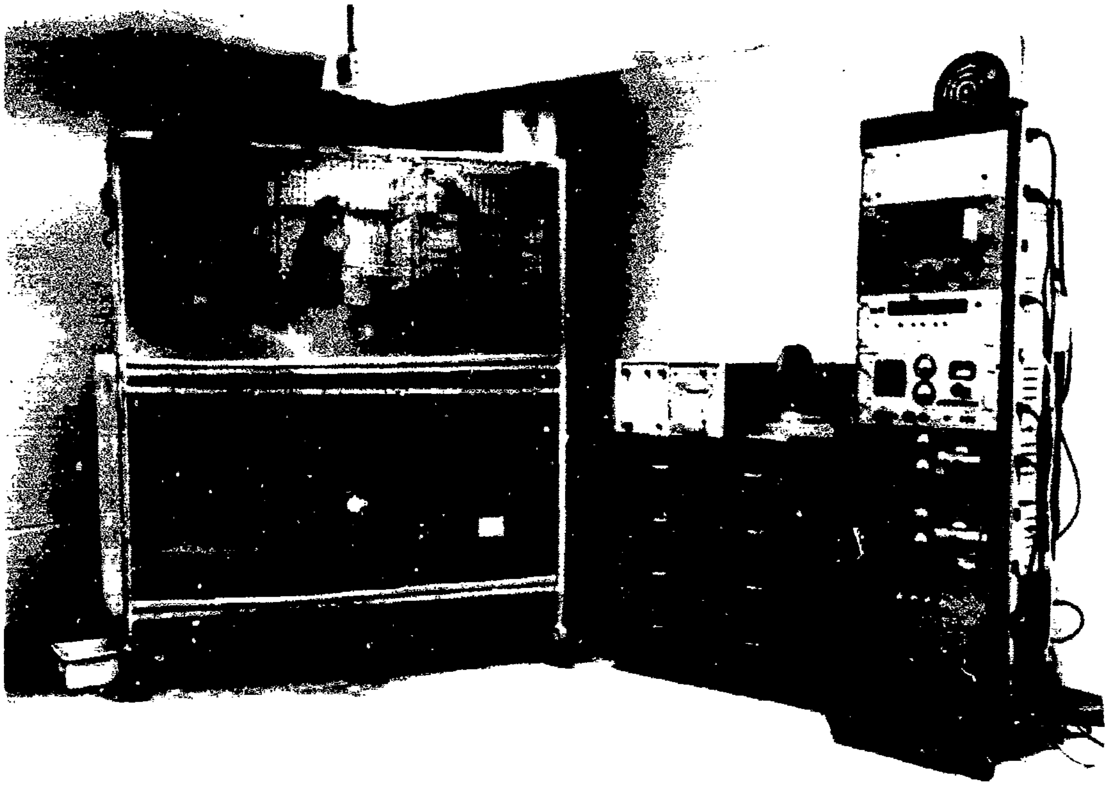


FIGURE 9

Temperature-sensing telemetry system in operation.

TABLE I

Operational life of implantable units used in experiment

Subject	Implants used to complete run		Number of days implanted	Total operational life (days)	Remarks
4H2	1	G	35	47	Calculated life: 70 days.*
6D3	2	E	23	25	Calculated life: 96 days.*
		B	25	104	Calculated life: 112 days.
7J4	3	J	17	26	Calculated life: 75 days.*
		1A	4	5	Cold solder joint.
		J	13	—	Removed from subject 7J4 and implanted in subject 8J0.
2J0	2	2A	32	38	Calculated life: 61 days.*
		3B	19	64	Calculated life: 90 days.*
3E9	1	2B	50	80	Calculated life: 75 days.
8J0	3	2C	3	3	Low output of subcarrier oscillator.
		J	35	50	Calculated life: 75 days.*
		3C	12	60	Calculated life: 84 days.

*Shortening of life due to moisture leakage or battery failure, or both.

was found that operational life of sensors implanted in the primate was much less and highly variable. Table I indicates subject, number of implants required to complete a run, and reason for implant failure, if known. We cannot pinpoint the reason for the shortened operational life of the implant. It may be attributed to batteries, moisture absorption, or a combination of the two.

A fibrous capsule is formed around the implant during the period of the run. The walls of the capsule are approximately 1 mm. thick. A measurement of the implant time constant, with and without the fibrous capsule, indicated a small increase (40 seconds maximum) due to the fibrous capsule. Theoretically, the fibrous capsule should not affect the core temperature measurements.

During the 5-week runs, 276 temperature readings were recorded per day for each subject. Less than 1% of these readings was lost owing to noise or signal dropouts. Figure 10 indicates temperature recordings obtained from the first group of primates over a period of 2 days.

The overall telemetering temperature-sensing system met the original criteria except for 50-day operational life. It appears that operational life is unpredictable, probably because of moisture leakage or batteries operating at a

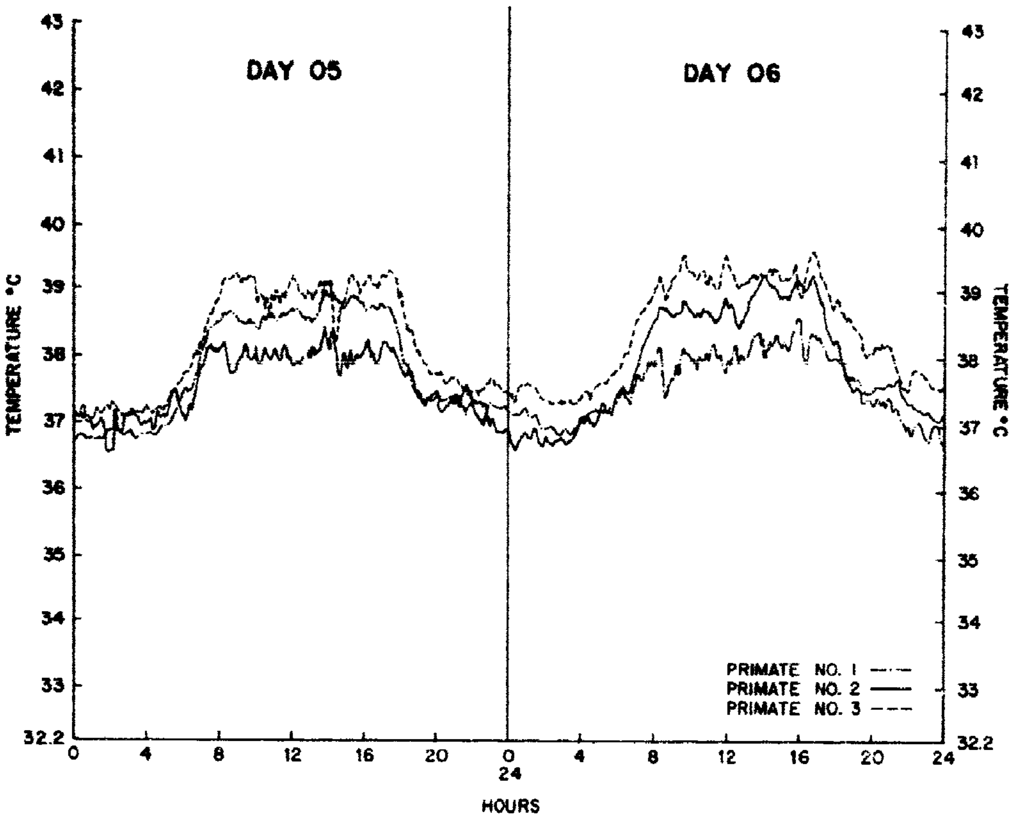


FIGURE 10

Diurnal temperature curve of three primates.

low current drain over long periods, thus resulting in globules of mercury (during cell discharge, mercuric oxide is reduced to mercury) migrating within the cell and causing internal shorts (4). Tests are continuing to determine cause of failure of implants to operate the calculated life span and, if possible, to improve reliability.

V. CONCLUSIONS

The temperature-sensing telemetry system described in this paper appears suitable for recording of varying physiologic temperatures from unrestrained animals. Especially appealing is the 0.1° C. resolution and the ease of operation of the system, which permits researchers with a life sciences background to easily master the operating procedures.

Although the implant satisfactorily transmits the data, the size and weight are greater than desired. Continuing work is being accomplished to develop a means of reducing the amount of power required by the unit, thereby decreasing battery size and weight.

Problems were encountered on implants not having the calculated operational life. Tests, which are still in progress, strongly indicate shortening of operational life must be due to either body fluid leakage, or batteries becoming short-circuited, or a combination of the two.

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13. ABSTRACT

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